An 'open system pingo' near Kangerlussuaq (Søndre Strømfjord), West Greenland

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Some of the most conspicuous structures generated in permafrost regions are pingos, conical hills containing an ice lens. Collapse structures of Pleistocene pingos are known from many sites in Europe (e.g. Washburn, 1973; Pissart, 1988), and active pingos have been described from the Antarctic, Siberia, Canada, Alaska, Spitzbergen and Greenland; in central West Greenland examples are found on Disko island and the Nuussuaq peninsula (Müller, 1959; Weidick, 1971, 1974; Scholz, 1984). No pingos have hitherto been reported from southern West Greenland, although the surficial geology of the region has been investigated in some detail (e.g. Weidick, 1968, 1974; Hansen, 1970; Hårløv *et al.*, 1980; Scholz & Grottenthaler, 1988; Dijkmans & Törnqvist, 1991).

This article describes a large and presumably active pingo discovered in August 1996 by the first author, east of the airport at Kangerlussuaq (Søndre Strømfjord) (Fig. 1).

The pingo: setting and morphology

'Leverett Glacier' is an outlet glacier from the Inland Ice, 25 km east of the airport at Kangerlussuaq, and the active pingo is located immediately in front of the glacier within a complex of crescent-shaped moraine ridges. The moraine ridges are unvegetated, and obviously related to 'Leverett Glacier'. They were most probably formed during the historical stages (Weidick, 1968, 1976; Stäblein, 1975; Ten Brink, 1975), and are hardly more than 200 years old.

The pingo is a cone-shaped hill with a rounded top, 15–20 m high and with a maximum diameter of 60–70 m. It is situated only 200 m west of the present ice margin of 'Leverett Glacier', from which it is separated by a sandy outwash plain (Fig. 1). Like the adjacent moraine ridges, the cone-shaped hill consists of sandy material with pebbles and boulders, of presumed glaciogenic and glaciofluvial origin. Viewed from the south the hill has a regular shape, with the uppermost parts of the slopes grooved by numerous radially orientated, shallow erosion furrows (Fig. 2). These furrows do not extend from top to base of the pingo flanks, but are concentrated on the upper parts of the slope. They may follow dilation cracks. None of the adjacent moraine ridges have either a comparable shape or similar furrow developments.

On the summit of the pingo there is a crater-like depression covered by gravel, and a spring producing about two litres of clear water per second. The crater is only visible from the north, where the crater rim is deeply incised (Fig. 3). The steeply inclined walls encircling the depression on three sides are covered by a layer of sand and gravel a few decimetres thick; clear ice is readily exposed by digging. The hill appears to preserve a core of pure ice, at least a few metres thick. However, as no drilling has been carried out, this estimate is speculative. Apparently penetrating the ice lens, the spring emerges from the centre of the asymmetrical depression, flowing downslope towards the northeast to form an alluvial fan on the lower slopes of the hill adjoining the outwash plain. The water has washed away the sand in the stream bed, which comprises pebbles and boulders. There is at least one other abandoned stream outlet, incised into the western side of the crater and traceable to the southern foot of the pingo (Fig. 2). The head of this abandoned outlet is two metres above the present crater bottom, demonstrating a subsequent progressive deepening of the crater.

The water: type, composition and source

In regions of continuous permafrost there is no groundwater circulation, and 'real' springs are generally absent (Stäblein, 1977). This is one reason why drinking water

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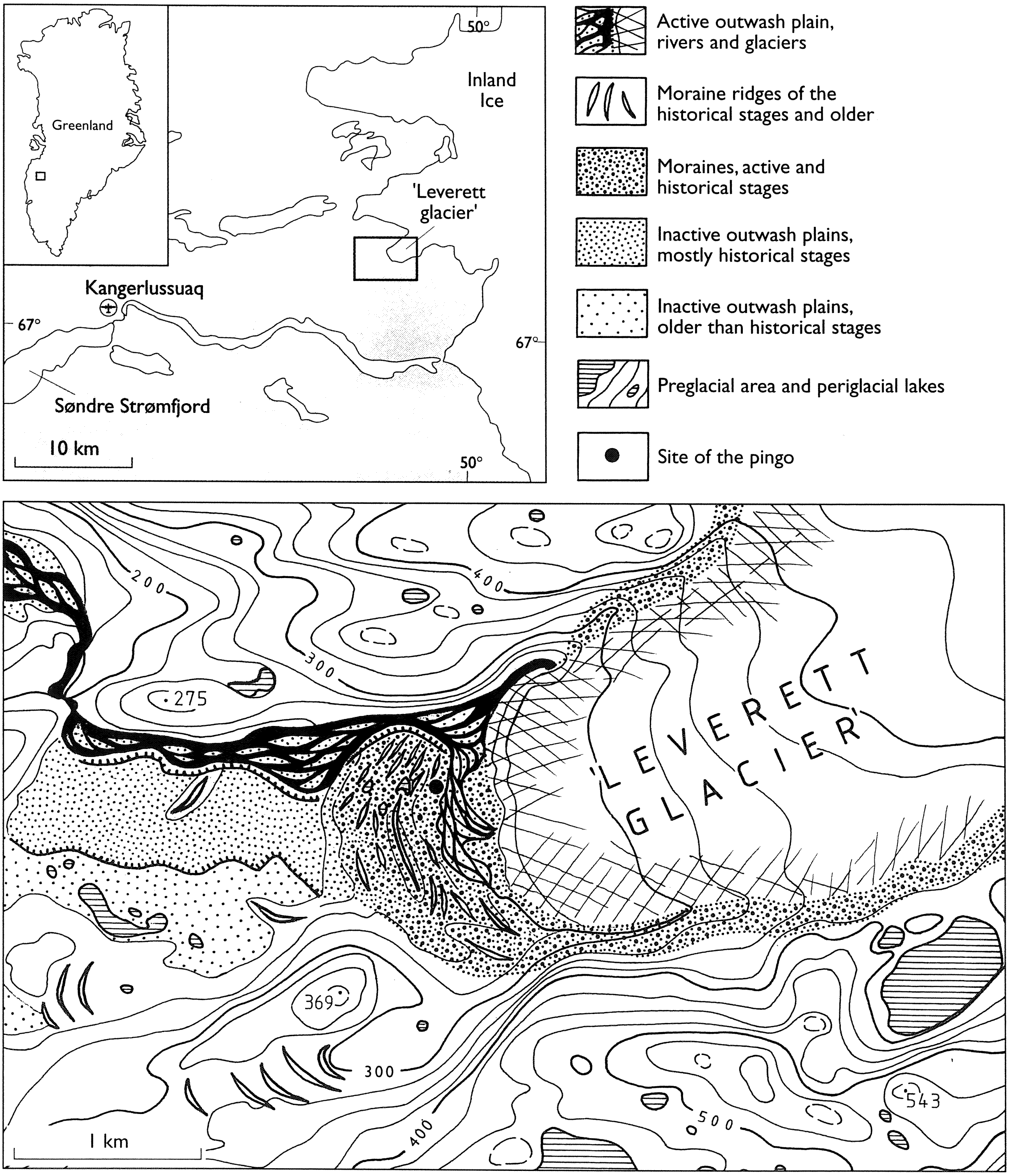

Fig. 1. Sketch map showing the site of the pingo in front of 'Leverett Glacier', an outlet glacier of the Inland Ice. The pingo is situated at the inner rim of an unvegetated moraine belonging to the historical stages. The map is based on a 1:100 000 topographical map (Greenland Tourism, 1995) and drawn from own geological observations (H.S.).

supply is a problem for many towns and villages in West Greenland. However, the water emanating from the pingo near 'Leverett Glacier' is undoubtedly a spring, and should be artesian as it rises from the top of a hill.

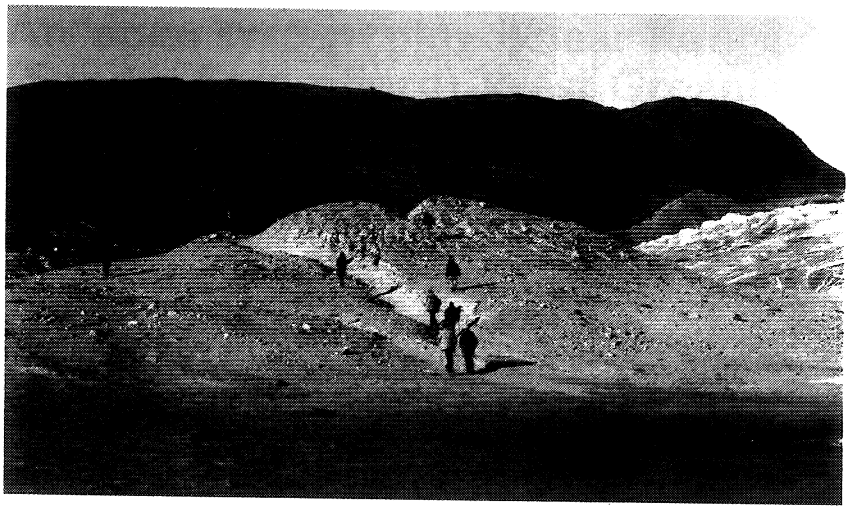

Fig. 2 . The southern side of the pingo illustrating the rather regular shape of the hill and the radially orientated shallow erosion furrows close to the summit. The small valley is an abandoned outlet traceable to the southern foot of the pingo partly filled with eolian sands. 'Leverett Glacier' is visible behind the pingo on the right.

Fig. 3. The northern side of the pingo showing the crater-like depression. The ice core of the pingo can be easily laid bare by digging at the lower part of the crater walls. A spring, originating in the centre of the crater, feeds a small brook that flows towards the north-east; pebbles and boulders in the brook bed are stained by rusty coatings. The abandoned outlet visible in Fig. 2 originates at the incision in the right side of the crater wall.

Artesian meltwater is, in fact, common in vegetated areas close to the ice margin in West Greenland. Water circulates through open shear cracks within the frozen ground formed due to the advancing ice, and intercommunicates with meltwater systems within the glacier ice (Scholz, 1991). However, although the spring in the pingo is only 250 m from the ice margin of 'Leverett Glacier', it does not produce typical milky meltwater. The spring water is clear, but evidently mineralised as the pebbles and boulders in the stream bed have a rusty patina; the water is undrinkable, with a distinct smell of hydrogen sulphide. No thermometer was available at the time of the observations, so the exact temperature is unknown; it felt rather cold.

A sample of the spring water was subsequently analysed (Tables 1, 2) at the Department of Hydrogeology, Hydrochemistry and Environmental Chemistry, Technical University of Munich by R. Nießner and M. Baumann. Due to the small size of the sample (100 ml), and the time difference between collection and analysis (respectively 7 August and 4 November 1996), the results should be viewed with some reservation due to the possibility of chemical alteration and dissolution of gas phases.

However, the chemical analyses confirm that the spring water is not meltwater. The high concentration of dissolved substances show it to be a Ca-Mg-HCO_3-SO_4-Cl type water, which can be described as highly mineralised compared with groundwater from other crystalline regions (Baumann, 1996). The high bromide, chloride and sulphate contents suggest the origin of the water is deep seated, probably deriving from faults in the crystalline rocks below the permafrost. As the water is apparantly able to penetrate the permafrost layer it may be of thermal (>20°C) origin; the relatively high content of fluoride (0.55 mg/l), aluminium and gold is typical for thermal water. Fluoride contents in cold groundwater from crystalline regions are normally not

Table 1. Chemical analysis of spring water sample: 'Leverett Glacier', West Greenland

1 litre of water	mg/l	equivalent mmol/l	equivalent %
Cations			
sodium	13.70	0.596	13.62
potassium	5.32	0.136	3.11
calcium	41.20	2.056	46.98
magnesium	19.30	1.588	36.29
Sum	68.52	4.376	100.00
Anions			
fluoride	0.55	0.029	0.67
chloride	39.13	1.104	25.49
bromide	1.14	0.014	0.33
nitrate	0.26	0.004	0.10
sulphate	70.90	1.476	34.09
hydogen carbonate	103.90	1.703	39.33
hydrogen phosphate	< 0.10	-	-
Sum	295.40	4.330	100.00
Temperature (not tested)	cold, but a few degrees above zero		
Electric conductivity	415 (µS/cm)		
pH	6.34		
Error of ion balance (%)	1.1		
Hardness (mmol)	1.8		
Hardness (°d)	10.2 (soft)		

Hydrogen sulphide may originally have been present, but has reacted with oxygen.

Table 2. Trace element content of spring water: 'Leverett Glacier', West Greenland

Ag	<0.1	Cr	1.70	Sb	<0.1
Al	451.40	Cu	5.39	Si	5.70
Au	0.30	Li	1.30	Sn	0.54
Ba	57.20	Mn	330.0	Sr	<100
Be	<0.1	Mo	1.49	Tl	<0.1
Bi	<0.1	Ni	4.00	V	4.10
Cd	<0.1	Pb	0.10	Zn	5.02
Co	0.80	Rb	7.50	Fe	6000

Elements are in µg/l

higher than 0.1–0.2 mg/l. During penetration of the permafrost layer any thermal water would have undergone cooling as well as possible dilution by meltwater; the water may once have been even more highly mineralised than the sample indicates. The presence of bromide and chloride may indicate contamination by seawater.

The ENE–WSW trending valley occupied by 'Leverett Glacier' follows a major fault line. This structure is part of a major fault system which forms the boundary zone between two Precambrian crystalline complexes of profoundly different age: the Nagssugtoqidian mobile belt to the north and the Archaean block to the south (Escher, 1971; Bridgwater *et al.*, 1976; Escher *et al.*, 1976).

Pingo formation

It is concluded that the pingo in front of 'Leverett Glacier' contains an ice core of frozen spring water, most probably derived from thermal water rising under pressure from faults within the crystalline basement below the permafrost layer. After penetrating the permafrost, whose thickness is uncertain, the water freezes within the glaciogenic/glaciofluvial deposits on the valley floor in front of 'Leverett Glacier'. The growth of the ice core, continuously supplied by water from below (an 'open-system' pingo; Washburn, 1973; Pissart, 1988), forces the sediments upwards to form a cone-shaped structure. The growing ice core appears to have caused the formation of radially developed cracks within the sediments, visible as the deep furrows around the crater rim. Erosion of the sedimentary cover may in time lay bare the ice core, which will progressively melt, leading to collapse of the pingo. The crater-like depression at the summit of the pingo suggests that the collapse-process may have already begun, thawing perhaps having been stimulated by the artesian water which rises through the ice core.

Closing remarks

It is surprising that the pingo at 'Leverett Glacier' has not previously been recognised, either by the first author who is familiar with the area, or by others. The pingo is a relatively large feature compared to the moraines in which it occurs, and 'Leverett Glacier', being close to Kangerlussuaq airport, has undoubtedly been visited frequently. The pingo is in fact clearly recognisable on photographs taken at 'Leverett Glacier' in the summer of 1986, when it seems to have had a shape very similar to the present. The site can also be identified on aerial photographs dating from 1968 flown for the Geodætisk Institut, Copenhagen.

The reason that the pingo has gone unnoticed for so long is probably connected to its unusual setting: the presence of an 'open system' pingo within a system of moraine ridges is unexpected. In studies of comparable areas in Europe affected by the Pleistocene glaciations, geomorphologists would interpret every depression as a stagnant ice structure, and hills as part of moraine systems. According to C. R. Burn (personal communication, 1997), there are several reports from Arctic Canada of ice-cored mounds in front of glaciers, for example on Baffin Island and Axel Heiberg Island. Thus, the discovery of the 'Leverett Glacier' pingo raises the question whether other pingos in similar moraine country in Greenland may also have been overlooked.

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